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13. ABSTRACT

Analysis of air gun signatures indicates that the signal is sufficiently repeatable to serve as a reliable, high-level, low-frequency sound source for at-sea experiments involving the device as a calibrated source. Development of computer programs for analyzing data was a significant part of this study, and the resulting program library should be helpful in future work requiring evaluation of impulse-type sound sources.

Details of illustrations in
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Illustrations

Abstract

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Problem Status

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Problem Authorization

BUBBLE FREQUENCIES OF AIR GUN SOURCES

Introduction

Impulse-type sound sources are being studied to determine their usefulness as signal generators for calibration measurements. This report describes acoustic measurements and analysis of data resulting from experiments performed with the NRL (PAR-type) air gun at the Underwater Sound Reference Division's Leesburg Facility.

The primary purpose of the experiments was to obtain sufficient data to characterize the predominant frequencies in and the equivalent source levels of the air gun acoustic signature as functions of chamber size and air pressure under conditions closely approximating those of a free field.

Seven air chambers ranging in volume from 1 to 40 in^3 were used in the gun at actuating air pressures from 500 to 2000 lb/in^2 in steps of 500 lb/in^2. Although it is virtually impossible to eliminate all of the reflections from boundaries of the confined sites in which the period required to record the signal is long in comparison with the reflection travel time, the effects of the reflections were minimized by the proper choice of distances with respect to the boundary conditions at the measurement site.

Computer programming required to process data from this investigation was extensive. The main software package consists of programs for data tape assembly, cross-correlation of data, curve averaging, fast Fourier transformation (FFT), Fourier spectrum interpolation, and data scaling. These programs are written in machine language for use on a Digital Equipment Corporation PDP-8/I computer. They are essentially magnetic tape oriented such that they can process large amounts of data with little interruption. Program tapes are stored in PS8 library format and can be called into the computer as needed *via* teletype instructions.

Description of Measurements

Figures 1 and 2 show the air gun as rigged for installation and its location with respect to the measurement hydrophones and water surface. Signals to be measured were initiated by means of the electrically activated solenoid triggering arrangement shown schematically in Fig. 3. Pressurized air is released explosively through the chamber ports as the released shuttle springs upward.
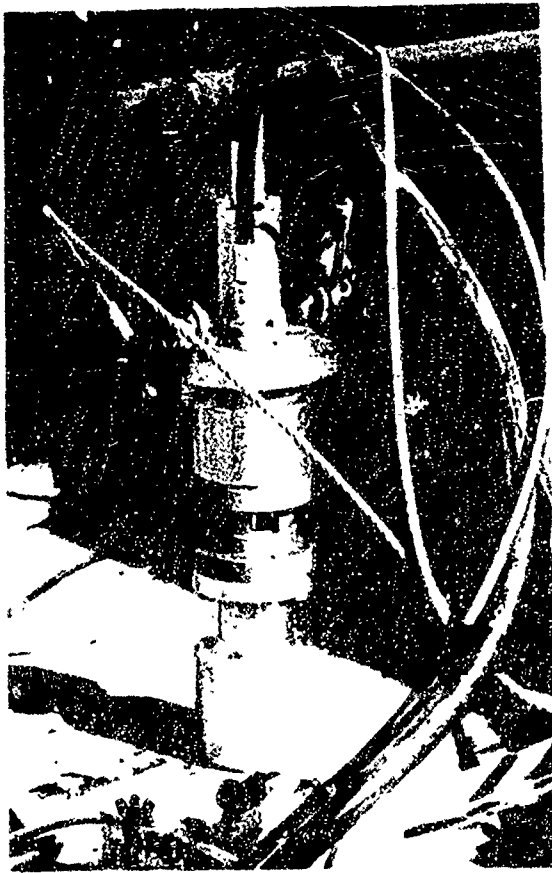
Fig. 1. Air gun as rigged for acoustic signature experiments.

For each set of experimental conditions, the initial shot was fired for preliminary oscilloscopic evaluation. Subsequent shots were fired at one-minute intervals to provide sufficient data for analysis. Earlier, 10 shots were made in each series, but as the repeatability of the signatures became evident by the time the $10\text{-}in^3$ chamber was installed in the gun, the number of shots per series was reduced to 5 (Fig. 4).

Acoustical data were recorded on two data channels that differed only by the hydrophone spacing to provide duplicate readings at different distances as a check on spherical spreading loss and to increase the confidence level of the data. One channel of the electrical circuitry for these measurements is shown schematically in Fig. 5. The gain of this circuitry is constant within ±0.5 dB in the frequency range from 15 Hz to 10 kHz,
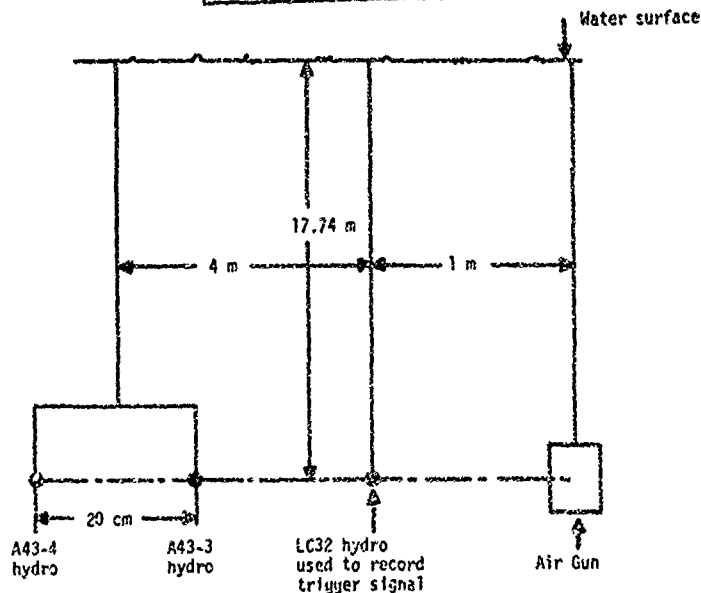

Fig. 2. Physical arrangement of air gun and measurement hydrophones. (Note: Surface reflection arrival estimated at 24 msec, sidewall reflection arrival estimated at 24 msec, and first bottom reflection arrival estimated at 50 msec, approximately 20-30 dB down.)
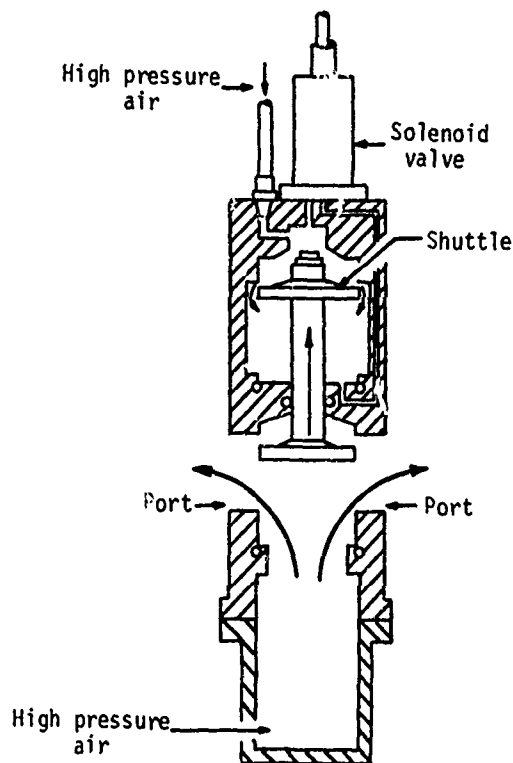
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Fig. 3. Sectional view of air gun showing air release by upward movement of shuttle.

and its dynamic range preceding the tape recorder is sufficient to receive a peak input of 0.04 V, which is more than adequate. This circuitry requires some attenuation adjustment to maintain signal levels within ±1 V at the tape recorder. Prefiltering was not used in either analog recording or later processing.

In addition to magnetic tape data recordings, photographs were taken at the input, and, in some cases, at the output of the tape recorder, with a storage oscilloscope and a Polaroid camera. Experimental data were obtained by photographing the oscilloscope trace for the initial shot of each series at the input of the tape recorder; the next shots in the series were recorded and stored in the storage oscilloscope. The
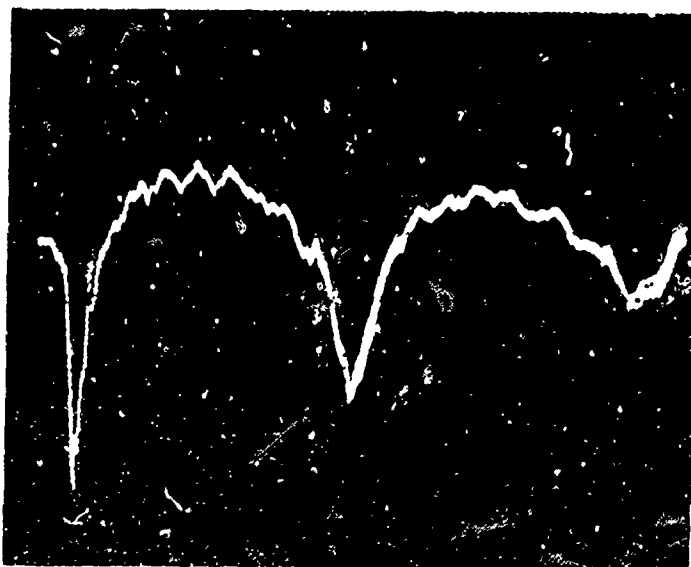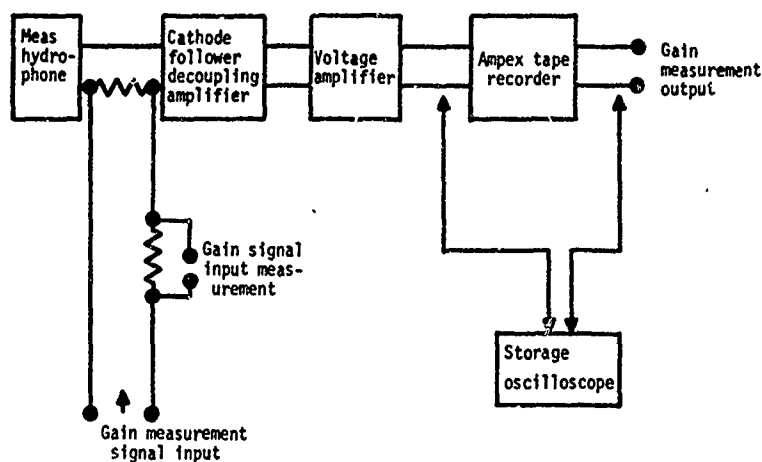

Fig. 4. Photograph of oscilloscope overlay of signatures from five successive shots of air gun with 10-in^3 chamber at 2000 lb/in^2 pressure. Time scale: one large division equals 5 msec.

Recording Information						
Tape ch. no	Record speed	Type record	Purpose	Hydro-phone	Ampli-fier	Cathode follower
4	60 in/sec	FM	Gun signature	A41 No.4	Scott No. 1	No. 3
5	60 in/sec	FM	Gun signature	A41 No.3	Scott No. 2	No. 4
3	60 in/sec	AM	Trigger signature	LC32	--	--
1	60 in/sec	AM	Voice	--	--	--

Fig. 5. Block diagram representing one data channel
for measurement of air gun signatures.

overlaid stored data displayed on the oscilloscope screen then were
photographed. A typical photograph of such a series is shown in Fig. 4.

Data Processing

Initial data processing entailed evaluation of the raw photographic
data to estimate the bubble resonance associated with each measurement
condition and the peak sound-pressure level produced. The next step in
data processing was a spectral analysis of the analog data by means of a
digital computer. At the start of the project, little of the available
software was suitable for this kind of analysis; consequently, its
development became a significant part of the study.

At first it was planned to digitize the analog signatures and write
a computer program that would average digitized signatures for each
experimental condition to obtain a curve that could be transformed to the
frequency domain by fast Fourier transform processing. It soon became
apparent, however, that because of erratic level changes in the trigger-
ing signal used to initiate the digitizing process, time coherence
between the individual digitized signatures was insufficient to permit
direct digital averaging. This problem was solved by developing a

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cross-correlation program to provide the best time coherence between digitized sets of data for averaging purposes.

Because the output of the digitizer was put on tape in record-channel sequence, it was necessary to develop a data assembly program for creating a new data tape containing the separated signals in their proper order for subsequent processing by the cross-correlation and averaging programs. The results of these programs then were passed through the FFT program, which has the capability for printing out either the magnitude of the line spectrum from each signature or the complex values as specified by program instructions. These outputs are stored on tape also, for use with a plotting program or for further analysis.

If, after FFT processing, spectra need to be examined in finer detail, they may be passed through an interpolation program that will, within a selected frequency range, provide the required interpolation and store these results on tape. Finally, all data and results can be related to a specified reference level by a logarithmic scaling program, which can produce both data tapes and printouts in decibel units.

Printouts are available at several points in these programs, as, for example, in the FFT and tape assembly programs. In addition, the averaging program computes the mean square deviation of each point of the averaged sets of data and outputs these results to tape.

Results

Figure 6 presents theoretical values of the air gun's bubble resonance frequency computed from Minnaert's equation for the oscillation of small air bubbles [1]. These values are approximately 22% higher than those measured for the 1- and 1.4-in^3 chambers, but are only about 3% higher than the resonance frequencies of larger chambers. For comparison, the results shown in Fig. 6 were weighted to correspond with data from the measurements made with larger chambers. Assumed in the computation are isothermal conditions and an initial energy equal to PV, where P is the gun chamber air pressure and V is the chamber volume. Figure 7 shows bubble resonance derived from photographic data. These results generally show the changes predicted by theory, except for that measured between the 1.4 and 5-in^3 chambers. This discrepancy cannot be explained at present. Figure 8 presents peak values of sound pressure as derived from photographic data.

Figure 9 shows the bubble resonances obtained by FFT spectral analysis. No data are given for chamber sizes above 10 in^3 because the results obtained by this method are not considered valid for the larger chambers. The unreliable results for the larger chambers are due to the choice of the digitizing rate used to convert the analog data. This choice was influenced by the fact that while the main resonances of the 1-in^3 cylinder range up to only 115 Hz, in general, the rise time of the signatures indicated a frequency content up to 5 kHz. It therefore appeared that the chosen digitizing rate should be sufficient to preserve
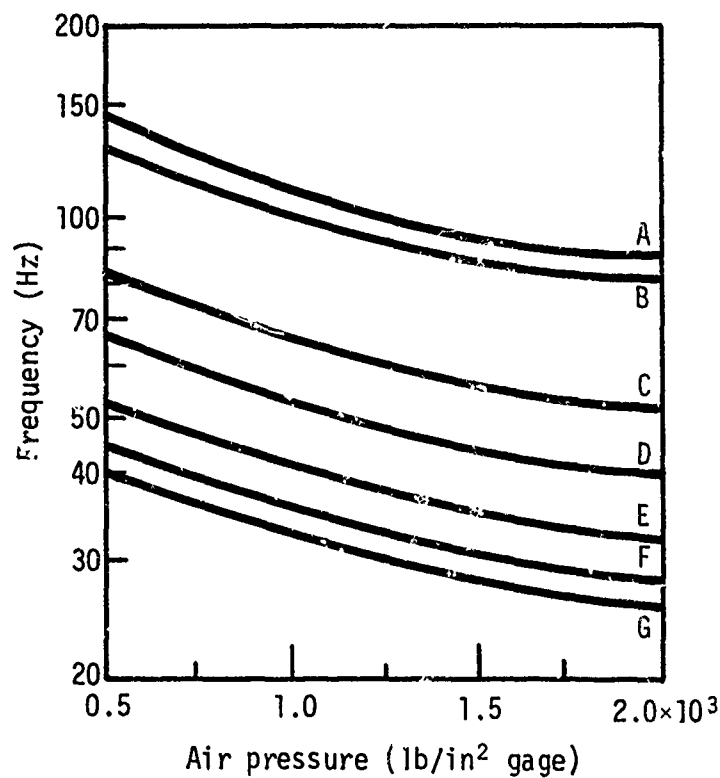
Fig. 6. Theoretical bubble resonance (adjusted) for various air gun chamber volumes; water depth corrected to 27.7 m. Chamber volumes (in^3): A, 1.0; B, 1.4; C, 5.0; D, 10; E, 20; F, 30; G, 40.
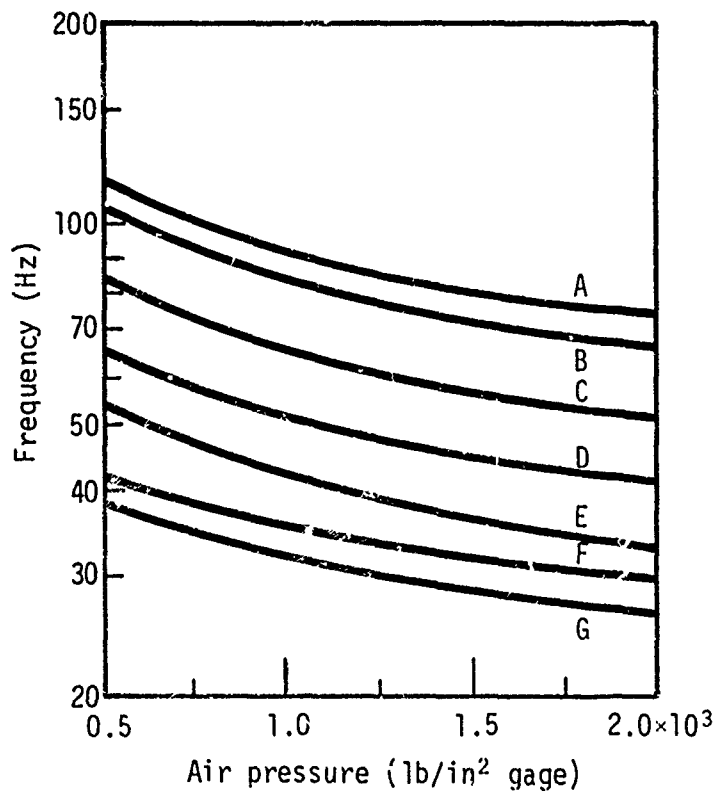

Fig. 7. Air gun resonance as measured from amplitude-time data *versus* air pressure; water depth corrected to 27.7 m. Chamber volumes (in^3): A, 1.0; B, 1.4; C, 5.0; D, 10; E, 20; F, 30; G, 40.

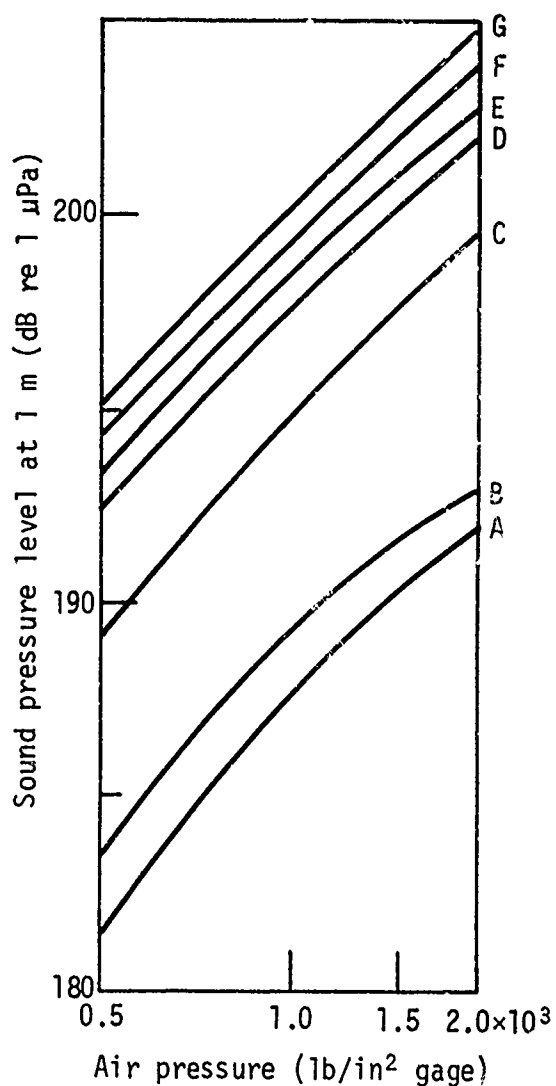Fig. 8. Peak sound pressure level of air gun shots *versus* air pressure. Chamber volumes (in^3): A, 1.0; B, 1.4; C, 5.0; D, 10; E, 20; F, 30; G, 40.
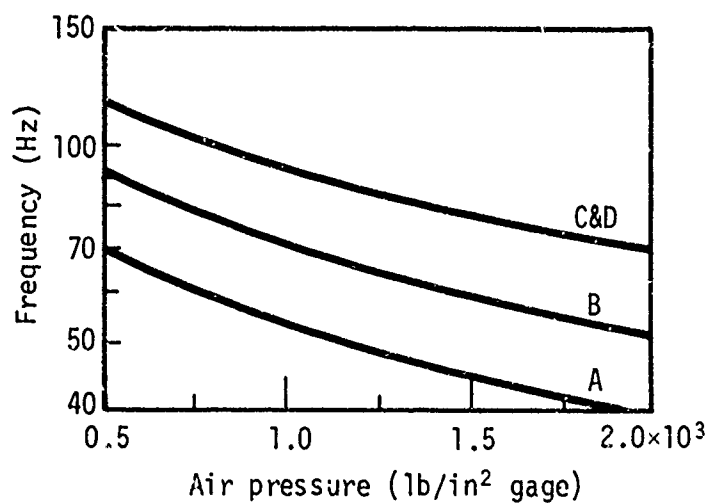

Fig. 9. Air gun resonance as measured *via* FFT *versus* air pressure. Chamber volumes (in^3): A, 1.0; B, 1.4; C, 5.0; D, 10.

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this signature frequency content. Because the signals produced by the gun were reasonably periodic, it was felt that it would be unnecessary to sample complete signatures obtained with the larger gun chambers. To preserve 5 kHz, a sampling rate of 10,400 words per second was chosen. This sampling rate, for the computer word-handling capability available at that time, resulted in a sample period of 0.1 sec, which is roughly one-half that of the signature period of th: largest chamber at the highest operating pressure. The results obtained indicate that the sampling period used was too short and caused blurring of the spectral data for the larger chambers. Also, no frequency separation is apparent between resonance data for the 1- and 1.4-in^3 chambers, even though the predicted separation of pressure levels for these signatures was obtained (Fig. 10). This effect may be the result of some high-frequency noise content in the analog signals. If the data were to be reprocessed, a lower digitizing rate and some low-pass prefiltering of the analog signals would be advised.
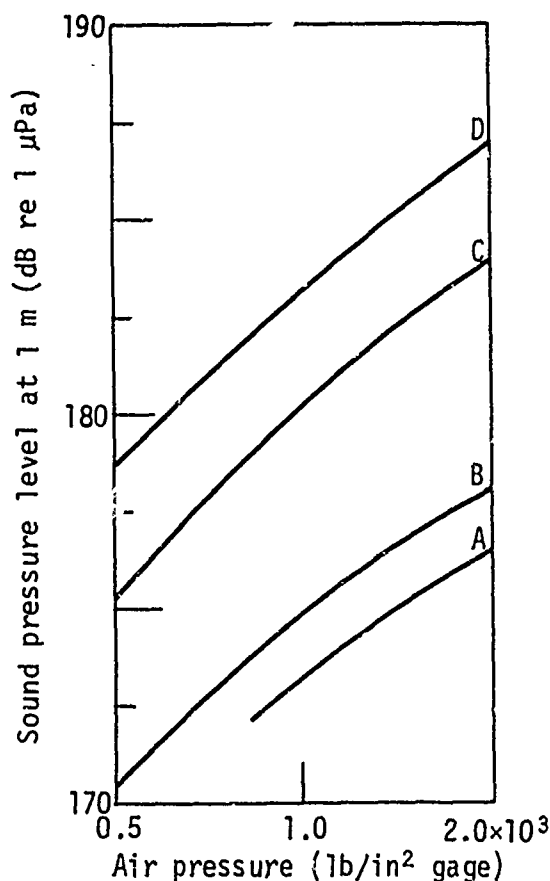

Fig. 10. Sound pressure level per hertz at resonance *versus* air pressure for various chamber sizes. Chamber volumes (in^3): A, 1.0; B, 1.4; C, 5.0; D, 10.

Figure 10 presents sound pressure levels at a distance of one meter from the source, as determined from spectral analysis. Pressure differences between the results for 1.4- and 5-in^3 chambers appear to be consistent with photographic findings that previously were shown to differ from theoretical predictions.

Conclusions

Results of these experiments confirm the feasibility of using the air gun as a calibrated high-level, low-frequency source in underwater sound experiments. Frequency and amplitude control may be exercised by selection of applied air pressure and choice of chamber size. The computer programming developed as a part of this problem will be useful in future evaluation of analog data from impulse-type sources.

References

[1] M. Minnaert, "On musical air bubbles and the sounds of running water," Phil. Mag. (7) 16, 235-248 (1933).